Invasive species threat to New Zealand: Asian Gypsy moth (*Lymantria dispar asiatica*).

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Introduction

The rates of biological invasions continue to increase globally (Seebens et al. 2021), causing significant disruption to ecosystems, habitat types and taxonomic groups (Essl et al. 2020). The transportation of species to regions beyond their natural range, is considered as a major driver of biodiversity change (Pyšek et al. 2020), such changes to biodiversity are most visible on geographically isolated islands, where high levels of endemism occur (Courchamp et al. 2003). New Zealand is considered a "biodiversity hotspot" due to its highly endemic biota (Myers et al. 2000), all of which have evolved in isolation from many of the invasive taxa present today (Allen & Lee 2006), and is a region which has been negatively affected by biological invasions (Simberloff 2019). In response to this, New Zealand is now widely regarded as a leading country on invasive species management and biosecurity (Simberloff 2019). In 1993, the Biosecurity Act was established, creating strict protocols around overseas goods entering the country in order to protect agriculture and biodiversity (Hulme 2020). Although costly, averaging $485 million NZD per year from 2017–2020 (New Zealand Government 2019), these protocols are implemented with the intention of avoiding greater future costs associated with managing or removing established invasive species. By examining Asian gypsy moth biological traits, regions of the world which are currently under invasion, and pathways of introduction, this study aims to determine if this species has the ability to establish in New Zealand, and the ecological impact the species could have.

Lymantria dispar asiatica biology

Lymantria dispar, also known as gypsy moths or spongy moths, is a species of moth in the family Erebidae. *Lymantria dispar is* subdivided into three (but possibly more) subspecies, *Lymantria dispar dispar* (European gypsy moth, EGM), *Lymantria dispar asiatica* (Asian gypsy moth, AGM), and *Lymantria dispar japonica* (Japanese gypsy moth, JGM) (McCormick 2019, Djoumad 2017). There is a degree of uncertainty over the classification, as the subspecies are notably difficult to distinguish from one another, each showing strong variation in colour, wing pattern, and genitalia characteristics. Comparative analysis of mitochondrial genomes conducted by Djoumad et al. (2017) showed potential usefulness in the identification of subspecies, however, the currently accepted biological distinctiveness is based upon sexual and functional dimorphism (flight capability of adult female moths), and distribution. The complete loss of flight ability in females is a key morphological trait that sets EGM apart from the other two subspecies. The females of AGM and JGM are flight capable and have comparatively larger wings and lower abdominal mass compared to EGM females, however, JGM's range is believed to be restricted to Japan (McCormick 2019).

Male AGM are comparatively smaller in size to the female (Fig. 1), antennae are bipectinated, abdomen is slender and brownish, forewings are very variable in colour, markings are brownish to blackish, with a thick darker band along the distal margin. Subbasal band near the costa, submarginal spots are variably developed V shaped marks, crescent shaped discal spot is also well-defined. Hindwings are yellowish to orange, usually with a darker band around wing margin (Horak et al. 2020).

Female AGM abdomen is yellowish to white, and darker in the last abdominal segments. (Fig. 1). Forewings are yellowish to white, with few and faint brownish markings. Usually, a few faint darker spots near base, subbasal band present as a curved brown mark near costa. Antemedial band is faint, originating from middle of costa and is sharply angled. Faint postmedial band, thin, zig-zag line, angled and roughly parallel to antemedial band. A row of small dark marks along outer margin, and brown crescentic discal marks are prominent. Hindwing whitish, with a series of dark small marginal spots, and a faint submarginal band (Horak et al. 2020). Adult moths do not feed, and live up to three weeks (Humble 1994).

Figure 1. *Lymantria dispar asiatica* imago, female (left) male (right). (Source: US Department of Agriculture, 2023).

Figure 2. *Lymantria dispar asiatica* female oviposting and egg mass (Source: University of Wisconsin-Madison, Division of Extension).

Female AGM emit sex pheromone cis-7, 8-epoxy-2-methyloctadecane soon after eclosion to attract males (Pogue & Schaefer 2007). This usually takes place during daytime, peaking in the late afternoon and followed by a secondary peak before midnight (Cardé et al. 1996). Oviposition behaviour is variable over the wide distribution of this subspecies, with members of each region preferring different biotopes (Pogue & Schaefer 2007). Across central Asia, egg masses are often placed on the underside of large pine tree branches (Fig. 2), while in Russia and Mongolia, oviposit in to crevasses on rocky outcrops, and occasionally directly on the soil under boulders (Hauck et al. 2008). These are sometimes found in such large concentrations, that egg masses are found on top of other eggs masses, each containing between 100-1000 eggs (Petrovskii 2010). In Siberia, egg masses can be found overwintering covered by accumulating snow. Experiments by Pogue and Schaefer (2007) found that those egg masses covered by snow are protected from extreme cold temperatures and desiccating winds, which caused significant egg mortality. They went on to conclude that temperature drops to the critical value of –29,9 °C leads to the death of 100 % of eggs, and the viability of eggs drops as they are exposed to longer periods of cold temperatures.

AGM are known to have one generation per year (Petrovskii 2010), and between six or seven larval instars. Laval dispersal is aided by "ballooning", larvae produce silk strands on which they suspend from, and are passively dispersed by the wind (Diss et al. 1996). Ballooning has been shown to allow larvae to travel around 5km per year to new infestations, but has been recorded at over 50km (ISSG 2023). Newly hatched caterpillars (2-3mm) are black and hairy, later developing to an easily recognisable final larval stage (60mm), usually charcoal grey but colour variation is quite common (Fig. 3). A double row of five blue and six red dots on its back, and a yellow middorsal longitudinal band extending along thoracic and abdominal segments (often faint). Setae are prominent along each abdominal segment, longer at the head and hind region (US Department of Agriculture, ISSG 2023). Larvae seek out protected locations when ready pupate, such as bark fissures, crevices and underneath loose moss. Pupae are dark reddish brown in colour, female pupae are usually larger (15-35mm) than male (15-20mm). The Pupal stages vary depending on sex, usually around 10 days for females and 13 days for males (Humble & Stewart 1994).

Lymantria dispar asiatica native range and ecological Impact

AGM is widely distributed throughout Asia, the Russian Far East, Mongolia, the northern two thirds of China, and the Korean Peninsula (Pogue & Schaefer 2007). AGM have an extremely wide host range, with over 100 known hosts, and have been referred to as 'superpolyphagous' because of this (Horak et al. 2020). Cyclic population dynamics are well documented, low population levels can exist for many years, periodically population's boom, causing extensive defoliation and damage until they decline. The natural enemies which occur in the native range of AGM, play different roles in regulating its populations. Birds feed on larvae, adults and egg masses during winter, rodents are reported to prey on larvae and pupae, along with spiders, assassin bugs, shield bugs and beetles (Baranchikov et al. 1998). More than 70 species, primarily tachinids (Fig. 4), ichneumonids, and braconids, have been reported to attack the gypsy moth in Asia. Most of these parasitoids affect the larval and the pupal stages, but a few can parasitize eggs (Baranchikov et al. 1998).

Lymantria dispar asiatica invasive distribution, ecological and economic Impact

Over a century since AGM's accidental introduction, North America (primarily the United States) (Fig. 5) has found AGM to be of serious concern, damaging both commercial and native forest ecosystems (Hajek & Tobin 2009). Population booms have led to the serious defoliation and weakening of trees and shrubs, often leading to tree death directly or indirectly by subsequent infestation by a secondary pest (Srivastava, 2020). The impact on crop yields, and economic costs associated with monitoring and controlling the invasive species are high. Eradication of two introductions in the early 1990's involved costs totalling US$ 34 million (Krcmar-Nozic et al. 2000). Long distance pathway vectors, primarily shipping and cargo containers arriving from ships arriving from ports of known to be within AGM's native range, are believed to be the source of establishment (Areces-Berazain, 2022).

Potential establishment of *Lymantria dispar asiatica* in New Zealand

The global shipping network is widely recognised as a pathway for vectoring AGM, and with the growing number of international ships whose first port of call to vulnerable ports (i.e., a port where AGM is established) before arriving in New Zealand, led to the Ministry of Primary Industries (MPI) launching a national trapping programme in March 1993. Monitoring of incoming goods from vulnerable ports has shown that in 2000 to 2002, 124 inceptions of AGM (107 egg masses, 9 larvae, 7 pupae and one adult) (Ross 2005), yet despite this, it was 10 years after implementation of the trapping programme that the first ever gypsy moth was discovered in the North Island city of Hamilton (MPI, 2023), and since then no further AGM's have been found.

Paini et al. (2018) used the Matsuki CLIMEX model to estimate those areas that are climatically suitable for AGM establishment (Fig. 6), showing conditions across North and South East New Zealand to be habitable. The strongest predictors and limitations of AGM potential range and dispersal being annual and seasonal precipitation, and regions which experience longer periods of temperatures ≥30 °C (optimum temperature conditions for AGM survival being 15- 25 °C) (Srivastava 2020). Yet the risk of AGM establishing in native forests may be low due to poor larval performance on native plants, with only one species of native tree (*Nothofagus solandri*) proving to be a successful host (Matsuki et al. 2001). The risk of establishment in urban environments and agricultural land, which support high quantities of exotic plants known to be host species, could be significantly higher (list of known hosts which are present in New Zealand are shown in appendix 1.)

Figure 3. *Lymantria dispar asiatica* caterpillar colour variation in final instar (Source: US Department of Agriculture, ISSG, 2023).

Figure 4. *Lymantria dispar asiatica* larva with tachinid eggs (white spots on dorsum) probably of Parasetigena sp. (Diptera: Tachinidae) (Source: P.W. Schaefer).

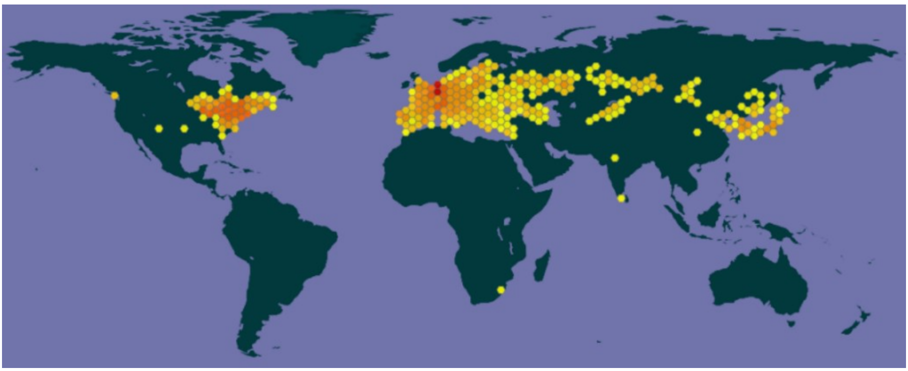

Figure 5. Global distribution of *Lymantria dispar asiatica*, showing native range across Eurasia and introduced range across North America (Source: Gbif.org, 2023).

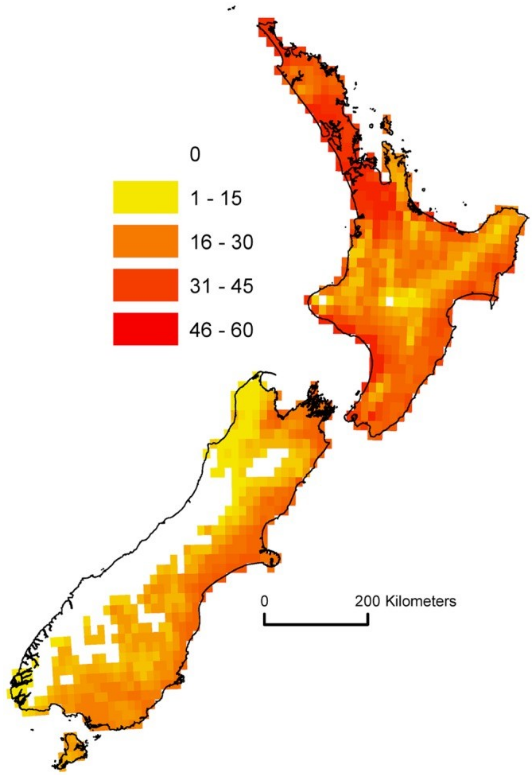

Figure 6. Climate suitability for gypsy moth (*L. d. asiatica*) in New Zealand modelled using CLIMEX Ecoclimatic Index (EI). (Paini et al. 2018).

There are a number of biological traits which provide strong dispersal methods, making AGM of even greater concern if becoming established. There is evidence to show that a proportion of AGM eggs do not undergo obligatory diapause and they hatch over a longer period, increasing the chance of introduction to new environments if pupae are undetected (Glare et al. 1998). The absence of natural enemies in New Zealand, decreases population suppression, increasing the potential long-term population fluctuations which are observed in North America, which is notable especially in the first few years after introduction (Glare et al. 1998). Larvae "ballooning" could drastically increase the initial range of establishment, and push the species in to new territory with ease. The volume of eggs which females are capable of ovipositing and the positing of these, could lead to populations surviving and thriving in areas of suitable hosts, proving very difficult to remove.

These findings suggest that surveillance, continued monitoring, and strict biosecurity checks are crucial to prevent AGM entering New Zealand's borders. Moreover, as the global patterns of AGM invasions continue, and likely advances and frequency of international trade to New Zealand persist, further trapping programmes across regions would be key to lowering the risk of establishment.

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Appedix 1

This list of known host plants of *Lymantria dispar* was sourced from the Subcommittee on Plant Health Diagnostics - National Diagnostic Protocol for *Lymantria dispar*. Taxa removed if not present in New Zealand.

Family	Genus	Biostatus
Leguminosae	Acacia	Exotic
Sapindaceae	Acer	Exotic
Betulaceae	Alnus	Exotic
Betulaceae	Betula	Exotic
Myrtaceae	Callistemon	Exotic
Betulaceae	Carpinus	Exotic
Juglandaceae	Carya	Exotic
Fagaceae	Castanea	Exotic
Corylaceae	Corylus	Exotic
Myrtaceae	Corymbia	Exotic
Ebenaceae	Diospyrus	Exotic
Myrtaceae	Eucalyptus	Exotic
Myrtaceae	Eugenia	Exotic
Fagaceae	Fagus	Exotic
Oleaceae	Fraxinus	Exotic
Pinaceae	Larix	Exotic
Myrtaceae	Leptospermum	Native
Hamamelidaceae	Liquidambar	Exotic
Sapindaceae	Litchi	Exotic
Rosaceae	Malus	Exotic
Fagales	Nothofagus	Native
Pinaceae	Picea	Exotic
Pinaceae	Pinus	Exotic
Platanaceae	Platanus	Exotic
Salicaceae	Populus	Exotic
Rosaceae	Prunus	Exotic
Pinaceae	Pseudotsuga	Exotic
Rosaceae	Pyrus	Exotic
Fagaceae	Quercus	Exotic
Fabaceae	Robinia	Exotic
Salicaceae	Salix	Exotic
Cupressaceae	Taxodium	Exotic
Malvaceae	Tilia	Exotic
Ulmaceae	Ulmus	Exotic
Ericaceae	Vaccinium	Exotic
Poaceae	Zea	Exotic